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13. ABSTRACT *(Maximum 200 words)*

This report summarizes research works on the following areas. (a) Measurements of cross sections for electron-impact excitation into the metastable levels of argon and number densities of metastable argon atoms have been completed. We also measured the disappearance rates of the metastable atoms after the electron beam is turned off and the observed decay modes are consistent with diffusion loss. (b) Electron-impact excitation of the vibrational levels of the $C^3\Pi_u$ electronic state of the N_2 molecule and the emissions produced by the excited N_2 molecules have been studied. The relative intensities of the various (v', v") bands in the electron-beam experiments are compared with those observed in a dc discharge. (c) A new novel method has been developed utilizing magneto-optically trapped atoms as targets for measuring electron scattering cross sections and applied to electron-Rb scattering. This new method has advantages over the conventional methods. (d) Further studies of cold trapped atoms have led to development of another novel technique, i.e., a new method for measuring total electron-impact ionization cross section using trapped atom targets. Application to Rb shows that this new method has advantages over the crossed-beam method.

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The research conducted under this project were directed toward understanding collisional processes between electrons, atoms, and molecules that are important in the atmosphere. Specific research works that have been completed are described in the following paragraphs.

1. The work on measurements of cross sections for electron-impact excitation into the metastable levels of argon and number densities of metastable argon atoms has been completed. We have obtained both the apparent excitation cross section and direct excitation cross sections for electron-impact excitation into the $3p^5 4s\ ^3P_0$, $^3P_2$ metastable levels ($1s_3$ and $1s_5$ in Paschen's notation) of argon. The number densities of the metastable atoms are measured by means of a transient laser-induced fluorescence (LIF) technique. This technique is also used to determine the disappearance rates of the metastable atoms after the electron beam is turned off. Two distinct decay modes are found and the observed behaviors are consistent with calculations based on diffusion theory.

2. Absolute optical emission cross sections have been measured for the second-positive band system of N_2, $C^3\Pi_u(v') \rightarrow B^3\Pi_g(v'')$, for v' = 0, 1, 2, 3, 4 and v'' as large as 9 produced by electron impact with the nitrogen molecule for incident-electron energies from threshold up to 600 eV. The relative cross sections for each v' family are in good agreement with the theoretical values. The measured optical emission cross sections enable us to determine apparent excitation cross sections for the v' = 0, 1, 2, 3, 4 vibrational levels of the $C\ ^3\Pi_u$ electronic states. A comparison of these apparent cross sections with the relative direct excitation cross sections predicted by the Franck-Condon principle suggests that the population of the $C^3\Pi_u$ state in an electron-beam experiment for the v' = 0, 1 and 2 levels is primarily due to direct excitation with minor contributions from cascade. For the v' = 3 and 4 levels, the direct excitation cross sections are much smaller so that a larger percentage population is attributed to cascade. The relative intensities of the various (v', v'') bands in the electron-beam experiments are also compared with those observed in a "dc" discharge. The relative total emission ratio for the $v^1 = 0$, 1, 2 levels in the discharge tracks very closely to the results of the electron-beam experiment, but large discrepancy is seen for the $v^1 = 3, 4$ levels. These observations are important for understanding the population mechanisms for the various vibrational levels of the C-state (electronic) in a dc discharge.

3. A new novel method has been developed utilizing cold magneto-optically trapped atoms as targets for measuring electron scattering cross sections. In our experiment ultracold Rb atoms are held in a magneto-optical trap at a temperature about 0.1 mK with 10^6 atoms inside a sphere of diameter approximately 0.5 mm. The trap (which consists of the cooling lasers and the

inhomogeneous magnetic field to keep the trapped atoms inside the small sphere) is turned off and a short electron-beam pulse is passed through the trapped atoms. When an electron is scattered by a Rb atom, the recoil velocity of the latter enables it to escape the trap. Thus by measuring the fractional loss of the Rb atoms due to electron beam bombardment, we determine the total electron scattering cross section (including elastic and inelastic). After the electron beam pulse is over we allow a delay time to lapse before turning the trap back on so that even atoms with a small recoil velocity have enough time to escape the trap. The fractional loss rates are measured with and without the electron beam, and their difference gives the fractional loss rate due to electron collision. The experiment is repeated using an increasingly larger delay time until we reach an asymptotic value of the fractional loss rate which, upon divided by the electron beam current density and multiplied by the electronic charge, gives the total electron scattering cross section. We have used this method to measure the total electron scattering cross sections for Rb atoms in the energy range of 7-500 eV. This new method has many advantages. The cross section depends on the fractional loss rate, but not the absolute loss rate. Thus only relative atom number measurements are needed. This point is important because the atom number density is difficult to measure for alkali atoms. Another advantage becomes apparent if we compare this method with the crossed beam method where an electron beam intersects an atomic beam and the cross section is determined by measuring the number of electron scattered at various angles. The crossed beam method is not suitable for small angle scattering because it is difficult to distinguish the nearly forward scattering from the incident beam. This problem is avoided in our new method of using trapped-atom targets. Here once we have reached the asymptotic value of the fractional loss rate, we know that scattering at all angles (including the forward scattering) is included in the result.

4. We have further explored the use of trapped atoms as targets for studying electron-atom collisions. This results in another novel development, i.e., development of a new method for measuring absolute total electron-impact **ionization** cross sections using a magneto-optical trap to hold the target atoms. In this experiment Rb atoms are cooled and confined to a small sphere (cloud) of about 0.5 mm diameter by a magneto-optical trap. The trap is momentarily turned off, and a pulsed electron beam is passed through the trapped atoms. The trap is turned back on immediately after the electron beam pulse. The Rb ions produced by electron-impact ionization do not respond to the cooling lasers and escape the trap whereas the non-ionized scattered atoms are recaptured and returned to the trapped cloud. The total ionization cross section is completely determined by the fractional loss rate of the trapped atoms and the electron beam current density at the location of the trapped cloud. We have used this new method to measure the total ionization cross sections of Rb atoms at energies from 50 eV to 500 eV. This new method has several advantages: (i) No absolute measurement of the number of trapped atoms is needed since the cross section is dictated by the relative loss rate.

(ii) Since the trapped cloud is much smaller than the electron beam, only the electron current density at the trapped cloud is relevant avoiding the difficult task of measuring the overlap of the profile of the electron beam with the profile of the atom beam hence eliminating a major source of difficulty in previous experiments. Indeed ionization cross sections reported by different groups have shown considerable variation and our technique provides a new approach to resolve discrepancies in these measurements.

5. Publications

(a) "Measurements of Cross Sections for Electron-Impact Excitation into the Metastable Levels of Argon and Number Densities of Metastable Argon Atoms" by R.S. Schappe, M.B. Schulman, L.W. Anderson, and C. C. Lin, Physical Review A **50**, 444 (1994).

(b) "Principles and Methods for Measurement of Electron Impact Excitation Cross Sections for Atoms and Molecules by Optical Techniques" by A.R. Filippelli, C.C. Lin, L.W. Anderson, and J.W. McConkey, Advances in Atomic, Molecular, and Optical Physics **33**, 1 (1994).

(c)"Electron Collision Cross-Sections Measure with the Use of a Magneto-Optical Trap" by R.S. Schappe, P. Feng, L.W. Anderson, C.C. Lin, and Walker, Europhysics Letters **29**, 439 (1995).

(d) "Electron-Impact Excitation of the Second Positive Band System ($C^3\Pi_u \rightarrow B^3\Pi_g$) and the $C^3\Pi_u$ Electronic State of the Nitrogen Molecule" by J.T. Fons, R.S. Schappe, and C.C. Lin, Physical Review A **53**, 2239 (1996).

(e) "Absolute Electron-Impact Ionization Cross Section Measurements Using a Magneto-Optical Trap", by R.S. Schappe, T. Walker, L.W. Anderson, and C. C. Lin, Physical Review Letters **76**, 4328 (1996).